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Stability in Mini-Grids with Large PV Penetration under Weather Disturbances-Implementation to the power system of Kythnos

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ABSTRACT

During the last decades, the continuously increasing demand for electric power as well as environmental aspects, have led to a growing penetration of Renewable Energy Sources to the power grid. The impact of this penetration in the total system behaviour is very important, especially in the case of weak grids such as the power system of the island of Kythnos. In this paper, a stability study of Kythnos island power system was investigated under power generation deviation due to solar insolation variations. The simulated model included all the components that usually appear in a mini-grid like diesel generators, three-phase transformers, PhotoVoltaic generators (PVs), passive and reactive loads and transmission line parameters. The system was tested under different scenarios of PV penetration and for a specific weather disturbance. In addition, simulation tests with 24-hour profile of solar irradiance were carried out. These tests reveal that the system becomes unstable or operates close to instability for high PV penetration. The simulation results show that there is enough time for the system operator in order to start-up back up generators or to take other measures.

1. Introduction

The basic aim of this work is the investigation of weak power systems which include Renewable Energy Sources (RES) and especially photovoltaics. More analytically, this study includes the examination of the dynamic behaviour of such a system. The power system of Kythnos was selected as a representative example [1, 2]. Kythnos is a Greek island which belongs to the cluster of Cyclades with 1500 permanent inhabitants electrified by an autonomous electric system.

The main parts of this work as they are presented in the following pages are two:

1) Investigation of the dynamic behaviour under a specific insolation disturbance due to cloudiness over the island. This group of tests include different penetration scenarios.

2) Investigation for 24-hour insolation profile with an associated 24-hour load consumption profile.

After the presentation of these results a paragraph with conclusions follows.

2. Power System Description

The power system of the island is shown in fig. 1. It is worth mentioning that currently the system includes one PV plant of 100kWp, located close to the diesel station. For the study some additional PV systems were considered. The latter are shown in fig. 1.

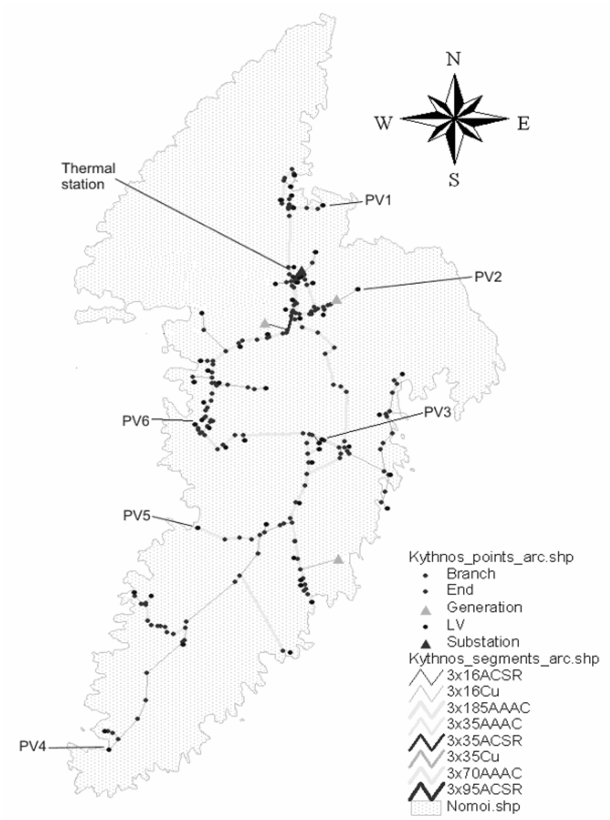


Fig. 1 The power system of Kythnos

The study was based on a Simulation model developed in Simulink which includes the following [2]:

- One thermal station consisting of five (5) Diesel-generators in parallel connection of 450kVA-400V nominal ratings operating in isochronous mode and connected to the bus via 3-phase Y/Δ step-up transformers of 0.4kV/15kV-500kVA.
- PV generators which were considered to be distributed in six different points of the grid.
- Power consumers are represented as Ohmic-Inductive or Ohmic loads.

3. Influence of a fast moving cloud over the island

The system was tested under a disturbance which was a sudden shadowing of the PV generators due to thick cloudiness. It was considered that the cloudiness was moving from north to south at a speed of 20km/h. By taking into account that the length of the island is 20km, it is evident that the cloudiness needs about 1 hour in order to completely cover the area from the northern to the southern edge of the island. It was also assumed that the length and the width of the cloud were long enough in order to cover completely the island (from east to west and from north to south). This results to a successive shadowing of the different PV generators and consequently the reduction of the PV generated power. It was assumed that the irradiance level was at the value of 100% (1000 W/m^2 = 1 Sun) before the shadowing and at the value of 25% after the disturbance. The load consumption during each simulation was taken constant. Moreover, the power generated by the conventional station, before the disturbance, was considered constant for all the tests, set at the value of 1280kW. This power is equally divided to the five separate diesel generators so that the power of each one is set at 256kW. The PV power which is generated is different for each test and varies as follows:

TABLE I: Distribution of PV units

Penetration	8,6%	16,7%:	33%	46,7%:	60%
Number and Power of PV units	3 of 13,3kWp and 3 of 26,6kWp	3 of 28,4kWp and 3 of 56,9kWp	3 of 71,1kWp and 3 of 142,2kWp	3of 124,4kWp and 3 of 248,8kWp	3 of 213,3kWp and 3 of 426,7kWp

Simulation results for four of the five different scenarios of penetration are shown in fig. 2. The fifth scenario (60% penetration) leads to instability. Because of this it is not depicted in fig. 2. Regarding the voltage sag variations, two different locations are presented, one at the output of the Diesel power station and the second at the extreme of the Medium Voltage grid, at the southern point of the island (Ag. Dimitrios). It is worth mentioning that the simulation step in these tests was chosen at 0.1 sec, Additional tests carried out with smaller time step (e.g. 0.01 and 0.001 sec) did not reveal any difference in the results.

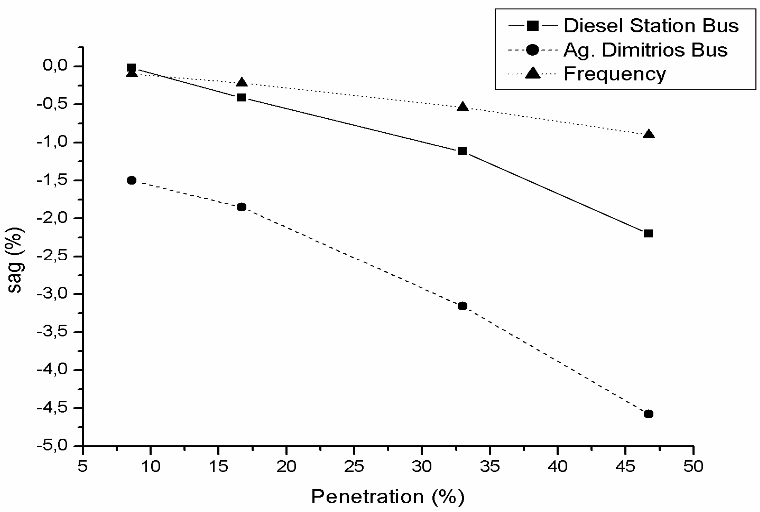
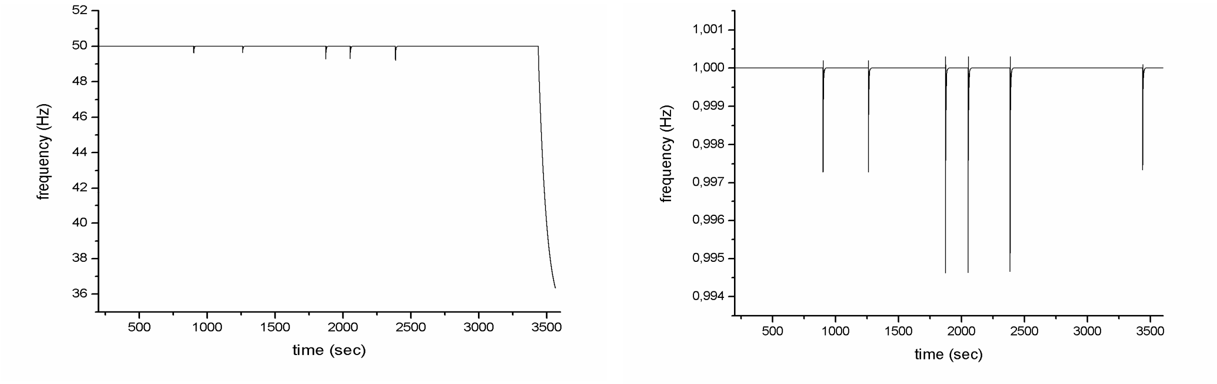


Fig. 2 Voltage and frequency maximum sag during the disturbance

Additional results of the frequency versus time are shown in fig. 3 for 60% and 33% respectively. From the simulation results, it is shown that the system is generally stable for penetration levels lower than 50% while it becomes unstable at higher levels of penetration due to insufficient spinning reserve of the diesel generators. Additionally, the time interval of the shadowing effect over the island was slow enough in order to cope with it. In case that a satellite observation forecast was used, then a 15 min advance notice, that cloud cover is eminent, would provide adequate time to start up the back up systems and avoid instability or black out events.



(a) **(b)**

Fig. 3 Simulation results versus time for 60% and 33% of PV penetration

According to standard EN50160 [3] for the connection of energy producers to the distribution grids, the adjustment for disconnection of the inverters in autonomous island grids in the Low Voltage grid should be set at -20% to +15% of the nominal voltage. With regards to the frequency the window outside the inverter should be disconnected is set at 51 Hz (+2%) and 47,5 Hz (-5%). Although these measures are taken for security reasons such concepts are not valid for large penetration distributed generation grids. In such grids, the distributed connected inverters should have larger windows of frequency and voltage operation in order to be able to ride through disturbances, i.e. voltage sag events, without loosing the production of inverter based generators, because otherwise the grid collapse is inevitable. Therefore, inverters designed with disturbance ride through capability are important for the future grids.

4. Discussion on the results-Measures of protection

It is clear from the above that the system has an efficient spinning reserve and consequently it retains its stability for all four cases from 8,6% to 46,7% penetration. However, in the case where the penetration increases dramatically (60%) the system becomes unstable when the last PV unit reduces its generation. It is obvious that the time interval during which the system is led to instability is approximately one hour. Provided that cloud speed is not too high (<80 km/hr) and direction is not unfavorable, then we may be able to cope with the disturbance. If we receive advance notice from earth observation satellites, or by other means, for fast approaching clouds then we may be able to manage the situation. This means that there is a considerable time for a prediction which would start up a back-up source in order to retain stability. It is worth mentioning that up to now Earth Observation has been mainly used for site assessment in the solar energy power plant planning phase and for solar energy potential analysis on a regional or national level [4]. Also, photovoltaic solar systems are routinely monitored by an ongoing comparison of actual power production and satellite-based estimates [5]. As a back-up power source it could be used either an additional diesel generator or a battery storage system with an appropriate battery inverter. The second case is more advantageous due to its the lower operating cost and the fast response in case of fast moving clouds or scattered clouds that do not lay a uniform shadow over the island. An additional solution could be the partial disconnection of non-critical loads or the introduction of load controllers and grid management techniques. A statistical analysis of historic weather data, especially the cloud speed variation and direction of movement may build a matrix of expected events and their frequency according to the various seasons over the island.

5. 24-Hour dynamic analysis

In this case, the study is extended to a 24-hour time range, during which the solar irradiance as well as the load demand of the grid vary. The assumed load curve is shown in fig. 4a. The ground solar irradiation profile is assumed from data taken at C.R.E.S. premises at Pikermi, Attiki, where significant cloud shadowing is observed. For each PV power station the irradiance profile is shifted in time according to the latitude of its location. In fig. 4b, the instantaneous PV power generation over the whole island is presented as a percentage of the instantaneous load. The maximum PV penetration exceeds 30% when there is no shadowing and it is reduced during the day time hours down to 3% during sudden shadowing of the PV generators due to thick cloudiness. As previously, it was considered that the cloudiness was moving from North to South at a speed of 20km/h. This results to a successive shadowing of the different PV generators from North to South and consequently the reduction of the PV generated power.

Regarding the voltage variation over the 24 hour simulation it is presented in figure 4c, for two different locations, one at the output of the Diesel power station and the second

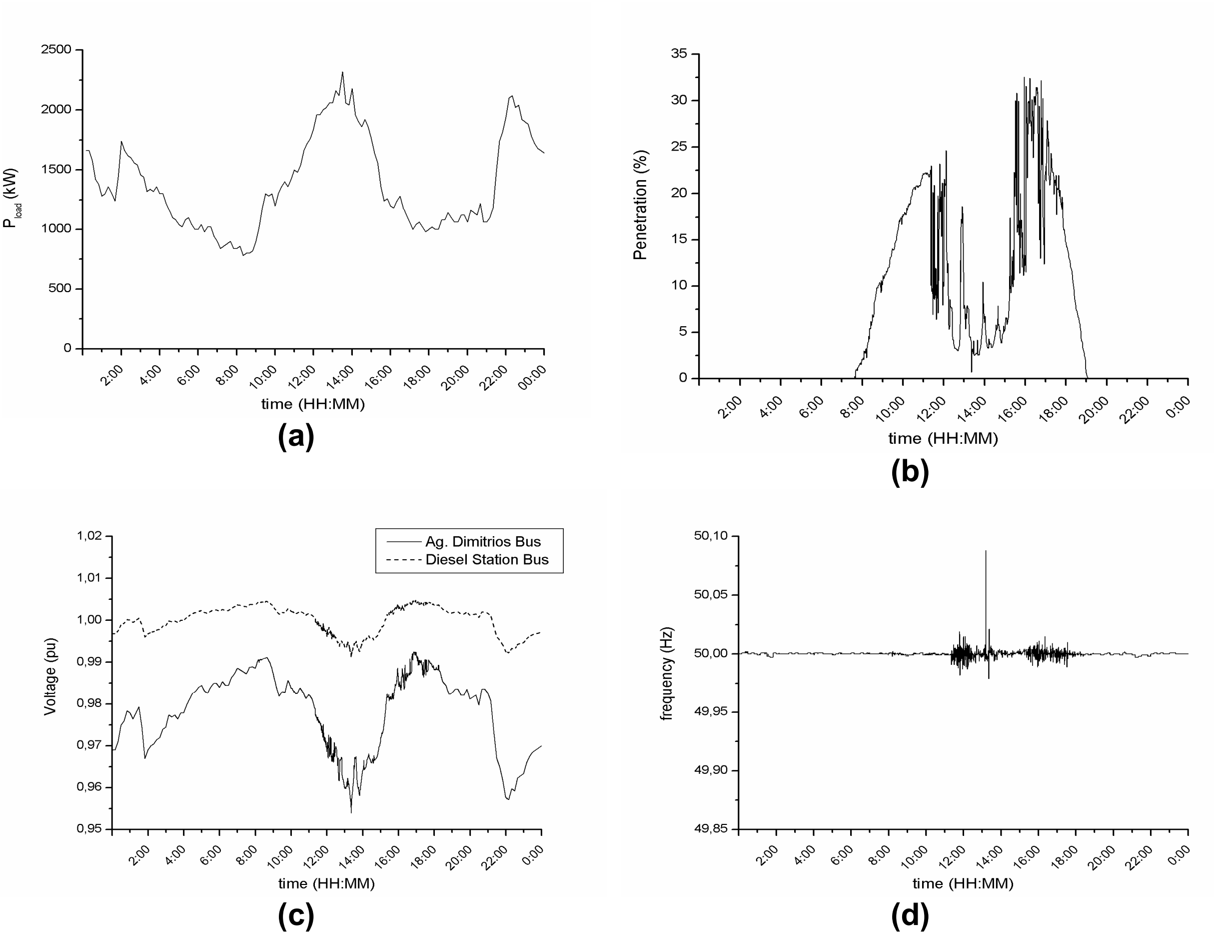


Fig. 4 24-hour load and penetration-simulation results

at the extreme of the medium voltage grid, at the southern point of the island (Ag. Dimitrios). The voltage drop during the heavy shadowing reaches 96% of the nominal value and the same drop is observed in the evening during the local maximum of demand. The reason we have such a high voltage drop at 14:00 and 22:00 is because the load exceeds the rated power of the available diesel generators. The frequency variations (figure 4d) during the 24 hour run seem to be minimal except during the time of high variability of the sun, between 12 and 18 hours, due to the clouds. In all cases the voltage and frequency where kept within the aforementioned specifications.

6. Conclusions

In this paper an analytical study of the dynamic response of the Kythnos power system is presented. The system is tested under insolation disturbances for different PV penetration levels. From the results it is obvious that there is instability for high penetrations while in some cases the system may operate close to its limit. Another important conclusion is that for relatively low cloud movement speeds (<80km/hr) and based on observation techniques it is possible to take advance protection measures such as the start up of back up generators to avoid instability. Further solutions that allow the large penetration of PV and other RES are the introduction of a storage system with an appropriate inverter, possibly combined with measures of disconnection of non-critical loads or the introduction of load controllers and grid management techniques.

References

[1]. S. Tselepis, A. Neris, *"Impact of increasing penetration of PV and wind generation on the dynamic behaviour of the autonomous grid of the island of Kythnos, Greece"*, 3rd European PV-Hybrid and Mini-Grid Conference Centre de Congres, Aix en Provence, France, May 11-12, 2006.

[2]. S. Tselepis, A. Neris, *"Dynamic behaviour of the autonomous grid of the island of Kythnos, Greece, due to large penetration of PV and wind systems"*, Proceedings of the 20th European Photovoltaic Solar Energy Conference and Exhibition, pages 2698-2701, 6-10 June 2005, Barcelona, Spain.

[3]. *EN 50160*, Voltage characteristics of electricity supplied by public distribution systems.

[4]. H. Brösamle, H. Mannstein, C. Schillings, F. Trieb, *"Assessment of solar electricity potentials in North Africa based on satellite data and a geographic information system"*, *Solar Energy*, Vol. 70, No. 1, pp. 1-12, 2001.

[5]. A. Drews, C. de Keizer, E. Lorenz, W.G. J.H.M van Sark , H.G. Beyer, E. Wiemken, W. Heydenreich, S. Stettler, P. Toggweiler, J. Betcke, S. Bofinger, G. Heilscher, M. Schneider, D. and Heinemann, *"Monitoring and remote failure detection of grid-connected PV systems based on satellite observations"*, *Solar Energy*, Vol. 81, No. 4, p.548-564, 2007.